ENERGY STAR Portfolio Manager
Methodology for Accounting for Weather

Weather can be an important factor in the energy performance of a building, and therefore it is a critical area for which EPA provides adjustments within Portfolio Manager. There are two key areas of normalization:

- **Energy Performance Ratings** - Adjustments performed when calculating energy performance ratings ensure that a building can be compared equitably with other buildings in the country, which may operate in either colder or warmer climates.
- **Weather Normalized Source Energy Use Intensity (EUI)** - Weather normalized energy consumption allows for a comparison of a building's energy use relative to itself over time, accounting for year-to-year differences in weather.

The purpose of this document is to provide technical detail on the methodology undertaken by EPA to incorporate weather adjustments within Portfolio Manager. It is organized into the following sections:

I. Energy Performance Ratings

Energy performance ratings are developed using regression models to provide a national benchmark. In the energy performance rating a ***relationship between weather and energy is established across a nationally representative sample***. This national response is used to provide a meaningful benchmark for a facility, when adjusting for the weather associated with its geographic location.

Rating Process

Energy performance ratings in Portfolio Manager normalize for the key drivers of energy consumption in different building types, which may include both operational characteristics and climate. The normalization allows buildings with different operating characteristics (e.g. greater or fewer employees) or buildings located in different parts of the country (cooler or warmer climates) to be compared equitably.

For each building type, a statistical regression analysis is completed to identify the key drivers of energy consumption. This equation will take the following form, to yield a predicted energy use for a building (Predicted Source EUI) given its operational characteristics:

$$\textit{Predicted Source Energy Use Intensity} = C_o + C_1 * \textit{Chararacteristic}_1 + C_2 * \textit{Characteristic}_2 + \ldots$$

Weather variables are incorporated as characteristics in this regression analysis. The variables analyzed generally include Heating Degree Days (HDD) and Cooling Degree Days (CDD)[1], as well as transformations of these variables (e.g. multiplying by Percent Heated or Cooled, using the natural log of HDD or CDD). Each coefficient (C_1, C_2, etc.) is a number that represents the correlation between the characteristic it describes and the building's source energy use intensity. For background on the technical approach to development of the Energy Performance Ratings, refer to *Energy Performance Ratings – Technical Methodology* (http://www.energystar.gov/ia/business/evaluate_performance/General_Overview_tech_methodology.pdf).

When conducting regression analyses, and when calculating energy performance ratings in Portfolio Manager, the ***actual*** reported energy use intensity and the ***actual*** HDD and CDD experienced by the building during the given timeframe are applied. Using actual values maintains the true relationship between weather and energy use for a given facility, and results in more accurate building ratings. Weather normalized source energy use intensity is ***not*** used in determining energy performance ratings. The method of using actual values inherently incorporates an adjustment for climate (different conditions in different locations) as well as weather (different conditions from year-to-year) in the energy performance ratings

Rating Example

To demonstrate the weather adjustments included in the rating models, energy performance ratings for two sample office buildings are included in **Table 1**. The table includes the operating

[1] HDD and CDD measure the deviation from a temperature of 65 degrees over the course of the year. For each day with an average temperature lower than 65 degrees, HDD is the difference between the average temperature and 65 degrees. The annual HDD is the sum of this difference across all days with an average temperature below 65 degrees. CDD is calculated in a similar manner, to measure deviations above 65 degrees.

characteristics for the two buildings, as well as the Predicted EUI, the Actual EUI, the EUI Ratio (Actual EUI / Predicted EUI), and the resulting energy performance rating. The rating model for office buildings includes two characteristics for weather: Heating Degree Days x Percent Heated and Cooling Degree Days x Percent Cooled.[2]

For illustrative purposes, the two sample buildings were chosen to have:

- The same operating characteristics
- Different weather (HDD is the same but CDD is different, to simplify the example)
- Different energy use
- *The same rating*

The example shows that the rating model normalizes for different weather conditions. Specifically in this case, the regression analysis for office buildings identified a correlation between EUI and CDD, due to the higher cooling load in warmer climates. In this example, the rating model provides a higher Predicted EUI for the office building with higher CDD. That is, the building with higher CDD is expected to use more energy, so it can have a higher Actual EUI and obtain the same rating. Note: This same principle would apply if the CDD were to vary from one year to the next for a single building, although the magnitude of the difference would likely be smaller.

Table 1
Energy Performance Rating Example

	Sample Office with Low CDD	**Sample Office with High CDD**
Square Feet	200,000	200,000
Weekly Operating Hours	80	80
Workers on the Main Shift	250	250
Number of Personal Computers	250	250
Heating Degree Days x Percent Heated	1500	1500
Cooling Degree Days x Percent Cooled	500	3000
Predicted EUI (kBtu/square foot)	***248***	***283***
Actual EUI (kBtu/square foot)	***202***	***229***
EUI Ratio	***0.81***	***0.81***
Rating	***62***	***62***

Weather Variables Included in Regression Analyses

There are numerous weather conditions that may influence energy use including: average daily temperature, temperature maximum and minimum values, humidity, and cloud cover. The weather variables used in EPA's statistical regression analyses are selected for two reasons: availability of data, and observed relationships in data.

[2] For details on the Office rating model, refer to *ENERGY STAR Performance Ratings – Technical Methodology for Office, Bank/Financial Institution, and Courthouse* (http://www.energystar.gov/ia/business/evaluate_performance/office_tech_desc.pdf)

The CBECS data set is used for the development of most rating models. To preserve confidentiality, the data does not reveal the exact location of each building. The most specific geographical division available is the census division (a total of 10 in the country). However, CBECS does provide for each building a value for HDD and CDD. HDD and CDD are common measures that reflect the heating and cooling requirement of a building, relative to the average temperature.

EPA includes HDD and CDD in statistical regression analyses, as well as transformations of these variables (e.g. multiplying by Percent Heated or Cooled, using the natural log of HDD or CDD). By including these variables in the regression analysis, EPA can estimate adjustments to reflect the typical relationship between HDD and energy intensity and between CDD and energy intensity. In most rating models, HDD and CDD are determined to have statistically significant impacts on energy use. Therefore, they are included and adjusted for in EPA ratings.

EPA performed analysis to determine whether humidity effects require additional adjustment beyond HDD and CDD. Because measures of humidity and dew point are not available in CBECS, these analyses required estimations. Through a series of estimations and regressions, EPA determined that a separate relationship for humidity was not statistically significant. Although removing moisture from the air requires energy, this energy requirement cannot necessarily be isolated in a specific building. The regression analysis simultaneously adjusts for each independent variable. It was observed that dew point is highly correlated with CDD. Therefore, in a regression analysis distinct statistically significant correlations for *both* CDD *and* dew point cannot be obtained. This indicates that the impact of dew point is accounted for by the inclusion of CDD variables in the analysis.

Most of the numerous weather characteristics that may influence a building's operation are correlated with each other. It is not feasible in a statistical analysis to identify separate adjustments for each characteristic. EPA's analysis reveals that HDD and CDD are good indicators of the weather conditions. Statistical correlations for these variables successfully account for weather differences across the country. Therefore, these are the only variables included in the regression analysis.

II. Weather-Normalized Source Energy Use Intensity (EUI)

Weather normalization is the process by which the energy use from one year is adjusted to account for specific weather conditions. Through this procedure, the energy in a given year is adjusted to express the energy that would have been consumed under 30-year average weather conditions. Whereas the ENERGY STAR score compares one building to its peers, the process of weather normalization ***compares a building to itself***.

Normalization Process

The methodology EPA uses to weather normalize building energy data is based on E-Tracker, a software tool developed by Dr. Kelly Kissock of the University of Dayton. Information on this tool is available at: http://www.engr.udayton.edu/weather/ (a copy of the tool may be downloaded for free for Educational or Non-Commercial uses). The initial code was updated by

EPA in 2007 to provide more streamlined calculations within the database. The basic steps of weather normalization are as follows:

1. Adjust Energy Data to fit Calendar Months – For each energy meter, energy use is divided into calendar months to enable Portfolio Manager to add multiple meters together and to compare energy with reported monthly weather data. To accomplish this, each meter entry is divided evenly into the number of days in the billing cycle and the energy use for each day is assigned to each month. For example, if the bill reports 120,000 kWh from January 16 to February 15, there are a total of 30 days in the billing cycle, resulting in 4,000 kWh per day. Because there are 15 days in each month a total of 60,000 kWh would be counted towards January and 60,000 kWh towards February. In order to obtain the total energy for both January and February the previous and subsequent bills would be required to account for the beginning of January and the end of February. These bills would be apportioned in the same manner.

2. Compare Monthly Energy use to Monthly Weather Data – Based on its zip code, a building's monthly electricity consumption is compared to the monthly average temperature. This comparison is illustrated with the blue diamonds in **Figure 1**.

3. Calculate the Correlation between Energy and Weather – Using the selected period ending date for a single 12 month period, a regression is performed to establish an equation that captures the relationship between energy and temperature. The result of this regression is shown as the red line in **Figure 1**. This line represents the **building's response to weather** (it will be different for every building).
    a. Note that if one month's electricity consumption is significantly different from the building's monthly average consumption (i.e., at least 50% higher or lower than the mean reported value in the 12 month period of analysis), that month's value is not included in the regression analysis.

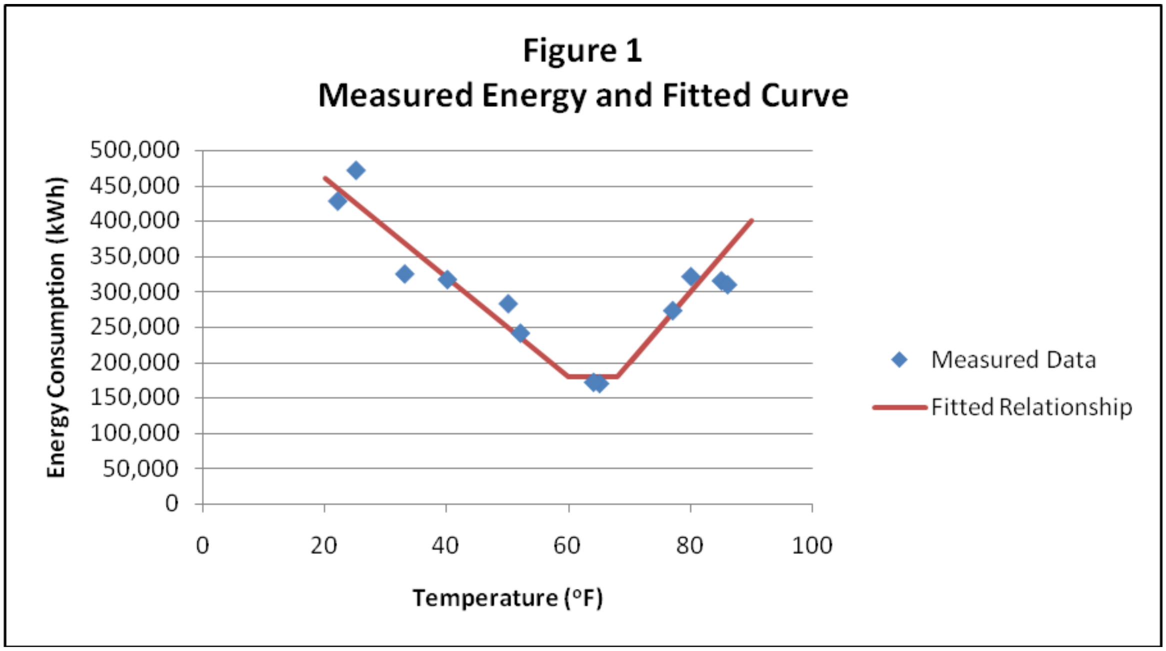
4. Compute the Equivalent Energy for 30-year conditions – The equation of this line is used to compute the energy use that would be associated with the 30-year average conditions. The 30-year average energy is computed for each month, and the total for all 12 months is summed together.
    a. For example, the energy consumption on the red line is 200,000 kWh at 70^{o}F. If the 30-year average temperature for July is 70^{o}F, then the procedure would predict that the building should use 200,000 kWh in July.

5. Repeat Steps 2 through 4 for Natural Gas – Steps 2 through 4 adjusted electricity consumption only. These same steps are repeated using the natural gas data to normalize the building's actual 12-month natural gas consumption up or down.
    a. The outlier test in Step 3 above is not performed for gas because gas usage can be more variable over the course of a year.

6. Convert Normalized Electric and Gas Consumption into Source Energy – The normalized values obtained in Step 5 will be in site energy, using the units entered (e.g. kWh). In order to convert this into source energy, the value is first multiplied by the standard thermal conversion to obtain site kBtu (e.g. 1 kWh = 3.412 kBtu). Once both electricity

and gas are expressed in site kBtu, they must be converted to source kBtu. While site energy use is the energy use associated with utility bills, source energy represents the total amount of raw fuel that is required to operate the building[3]. Each fuel has its own conversion factor (multiplier) that converts a value from site energy (kBtu) to source energy (kBtu). The factors to convert electricity and natural gas are 3.34 and 1.047, respectively.

7. Sum Normalized Source Energy use Across All Fuels and Divide by Square foot – The normalized electric source energy, normalized natural gas source energy, and the source energy use associated with any other energy consumption are then added together to determine the building's weather normalized source energy consumption. The weather normalized source energy use is divided by the total building square foot to yield the Weather Normalized Source EUI.



The process of weather normalization requires accurate monthly energy data, because this data is matched with the monthly temperature data. Therefore, Portfolio Manager cannot weather normalize energy data entered as a single value covering several months or more (e.g. when one annual value is entered). Buildings with any electric data entries that cover more than 65 days are not be able to see a weather normalized value. For the same reason, normalization is not attempted on fuels other than electricity or gas because actual monthly consumption is typically not known (e.g. there may be one annual delivery of fuel oil). Although these fuels cannot be normalized, they are still included in the total energy consumption.

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[3] For more detailed technical information on source energy, including references and assumptions for all of the factors, please refer the *ENERGY STAR Performance Ratings: Methodology for Incorporating Source Energy Use*, available at: http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_benchmark_comm_bldgs

Normalization Example

Using a specific example plotted in **Figure 1**, **Table 2** shows the actual monthly temperature and energy data and the monthly 30-year average temperature values. From these 30-year average temperatures, the normalized 30-year average energy is shown for each month. These values are calculated from the equation of the red line in **Figure 1**. **Table 3** illustrates how these total annual values in kWh are converted into Source EUI for the building.

In this example, the actual weather was colder than the 30-year average; temperatures are below 30^{o}F for January and February, while the 30-year average temperature for the climate is in the 30-40^{o}F range. Similarly, the actual temperatures in the summer were hotter than normal, showing 86^{o}F for the month of August, while the 30-year average is only 78^{o}F. Due to severe weather, this building has an actual energy consumption of over 3.6 Million kWh. But, its weather normalized value is only about 3.2 Million kWh. The weather normalized value is lower because had the temperatures been more typical for the climate, the building would have used much less energy.

Table 2
Weather Normalization Summary Example –
Part 1 - Computing Weather Normalized Site Energy

Month	**Actual Temperature**	**Actual Electricity (kWh)**	**30-Year Average Temperature**	**Weather Normalized Electricity (kWh)**
January	25	471,750	33	369,000
February	22	428,160	39	327,000
March	33	324,720	47	271,000
April	50	282,500	56	208,000
May	65	169,200	66	180,000
June	77	272,700	77	270,000
July	85	315,000	79	290,000
August	86	309,600	78	280,000
September	80	321,000	71	210,000
October	64	171,000	59	187,000
November	52	240,720	49	257,000
December	40	316,800	40	320,000
Annual Totals	Actual Site Energy (kWh)	3,623,150	Weather Normalized Site Energy (kWh)	3,169,000

Table 3
Weather Normalization Summary Example –
Part 2 – Computing Weather Normalized Source EUI

	Actual Value	Weather Normalized Value
Site Energy (kWh)	3,623,150	3,169,000
Site Energy (kBtu)	12,362,188	10,812,628
Source Energy	41,289,707	36,114,178
Actual Source EUI	***206.5***	***180.6***

Note: This calculation assumes a building that is 200,000 square foot in size.

Types of Weather Relationships

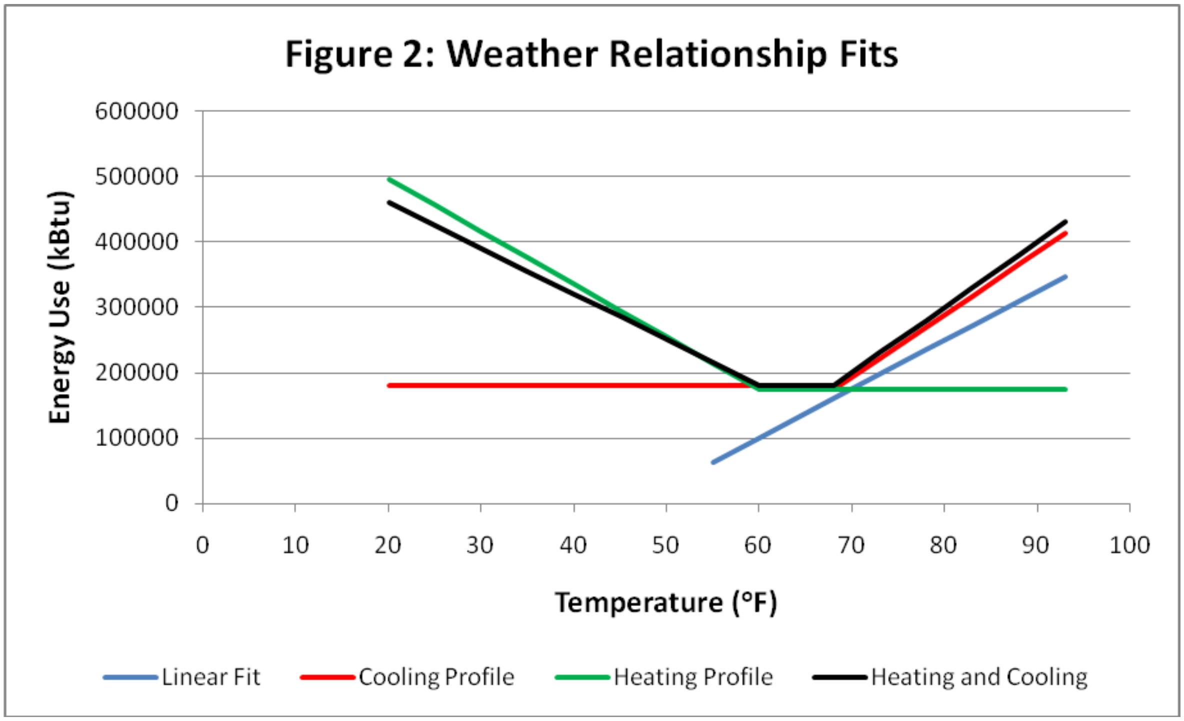
The preceding example illustrates a building that uses 100% electricity. As such, the electric use is higher in both colder and hotter months, with an average value in the middle. This is one of several types of weather relationships.

Another building may use electricity for cooling and natural gas for heating. This building would be expected to have higher natural gas use in the winter, with no change in gas consumption when temperatures get hotter, while it would have electricity that is constant in the winter (cold) months but increases in hot months. For this reason, one fit is performed for electricity and another for natural gas; and these two fits will have different shapes. The shape of the fit is influenced not only by whether the fuel is being used to heat or cool, but also by what climate the building is located in. For example, in a climate zone with zero heating degree days there is no cooling, and there may not be a period when no HVAC is used. If cooling equipment is needed in all months, the relationship will be a linear relationship that increases with increasing temperature.

The regression performed in Step 3 cycles through four types of fits to find the fit with the highest R^2 (the best correlation). Each fit type is described below and shown in **Figure 2**.

- <u>Linear Fit</u> – A linear fit shows a fuel that has a constant slope upward or downward. This means the fuel increases with increasing temperature or decreases with increasing temperature but never goes the other way. This type of relationship might be expected in a very hot climate where cooling occurs in all months; or in a very cold climate where heating occurs in all months. There is no base or “flat” period without conditioning.
- <u>Cooling Profile</u> – The relationship for a fuel that is used to cool, which is expected to be flat when temperatures are cold, but then at some point (e.g. 68^{o}F) degrees), energy will show a linear increase with additional energy for each degree.
- <u>Heating Profile</u> – The relationship for a fuel that is used to heat, which will show a high energy in cold months, with a negative slope (decreasing energy) as temperatures climb. Above a certain point (e.g. 65^{o}F), energy will remain constant because this heating fuel is not influenced by warmer temperatures.
- <u>Heating and Cooling</u> – When a single fuel is used for both heating and cooling it will show higher energy values at very low temperatures and higher energy at very high temperatures. There will be a minimum, smaller amount of energy used at moderate temperatures.

If none of these fits are found to have an R^2 value of 0.7 or higher, then it is deemed that there is no relationship between outside temperature and energy use. In these cases there is no normalization, which means the “weather normalized energy” displayed in Portfolio Manager will be the same as the actual energy use. Although this is not typical for commercial buildings, it can happen in buildings with very high internal loads. For example, hospitals or data centers may have so much equipment running at all times that the buildings show little or no response to outdoor temperatures.



III. Source Data

Data used for weather adjustments is obtained from the National Climatic Data Center (NCDC), an agency in the National Environmental Satellite, Data and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration (NOAA). Two data sets from NCDC are used:

- **Global Surface Summary of the Day (GSOD)** – This data set provides daily temperature, precipitation, air pressure and wind speed observation data for weather stations from around the globe. The data is updated daily on the NCDC web and ftp sites, at http://www.ncdc.noaa.gov/cgi-bin/res40.pl?page=gsod.html.

- **U.S. Climate Normals** – This data provides normal weather data over 30-year periods. The data can be accessed at http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

While NCDC has a large number of weather stations, EPA only uses a subset of these stations that have been determined to have reliable daily weather data. The list includes 157 U.S. cities, and can be found at http://academic.udayton.edu/kissock/http/Weather/default.htm.